TECHNICAL REPORT SIT-DL-02-9-2812

October, 2002

Ferry Wake Wash in NY/NJ Harbor

by

Michael Bruno, Brian Fullerton and Raju Datla

Prepared For

New Jersey Department of Transportation

(SIT-Davidson Laboratory Project No. 525400)

This material contains information which is communicated in confidence and should not be divulged without the consent of the person or organization for whom it was prepared.

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STEVENS INSTITUTE OF TECHNOLOGY DAVIDSON LABORATORY

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ABSTRACT

The Davidson Laboratory was contracted by the New Jersey Department of Transportation to study the wake wash issues in the New York harbor. The study is mainly concerned with the wake characteristics of ferries run by the NY Waterway, which is the largest commuter ferry operator in the region.

The study consisted of two phases – field studies and physical model studies. The field study was further divided into two parts. The first part was concerned mainly with a qualitative observational study of NY Waterway ferries in operation. In the second part, measurements were made of surface elevation time history near a marina using a pressure gauge to obtain more quantitative information about the wake wash. The physical model study involved measuring wake wash of small-scale models in the Laboratory towing tank.

Based on these studies, several conclusions and recommendations are presented.

INTRODUCTION

The wake wash generated by vessels has become an issue of international importance, especially for densely populated and active harbor areas. Some of the main concerns are:

- Safety of passing vessels, particularly small craft
- Impact to vessels in exposed and partially-protected dock areas and marinas
- Safety of passengers unloading from other ferries at harbor terminals
- Damage to bulkheads and other shoreline structures
- Erosion of natural shorelines and wetlands
- Biological impacts on offshore kelp beds and clam beds

The waves generated by high-speed craft are in general not very large compared to storm waves. However the high occurrence due to regular ferry service over a long period of time can cause disturbance to marinas, shoreline and seabed, in particular in shelter bays, channels and sounds. Also, to realize the full potential of high-speed ferries in satisfying the urban transportation needs, it is necessary for ferry vessels to maintain a high-speed for as long as possible between the origin and destination points. When the operating zones happen to be in close proximity to shores/banks and other water users, as is the case most often in urban harbors, this poses potentially significant safety and environmental challenges. Rapid growth rates in the high-speed ferry fleet in the New York/New Jersey Harbor area have added to the urgency of this challenge.

Description of Vessel-Generated Waves

The pattern of gravity waves created by a moving disturbance in deep water was determined by Lord Kelvin in 1887. Figures 1 and 2(a) show this classic pattern of diverging and transverse waves. This pattern exists up to a depth Froude number Fn^d (defined as Fn^d = V/sqrt(g D), where 'V' is the ship velocity, 'g' is the acceleration due to gravity and 'D' is the water depth) of about 0.6. As Fn^d increases due to either an increase in speed, a reduction in water depth or both, the longer wave components in the wash start to feel the

bottom and the wave properties begin to change. At the critical Froude number of Fnⁿ=1 (Figure 2b), the transverse waves disappear and the divergent waves form a wave of translation. In the super critical region, where Fnⁿ is greater than

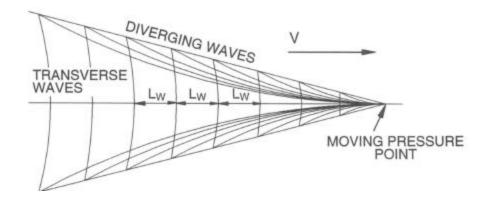


Figure 1. Kelvin Wave Pattern

1 (Figure 2c), the long waves with their speed limited by the water depth subtend an angle θ to the track of the ship so that $C = V \cos \theta$, where C is the phase speed = sqrt(g D) of the waves.

Objective

The main objective of this study was to assess the wake wash characteristics and associated impacts of ferries operated in the New York/New Jersey Harbor. Since the NY Waterway ferry service (Figure 3) is the largest operator in the harbor, we concentrated almost exclusively on their fleet. We here note the assistance provided by NY Waterways during the production of this report. It was with their assistance that much of the data presented herein was made available. The second objective of the study was the development of strategies to minimize adverse impacts identified in the first stage of the study.

Methodology

The study of ferry generated wakes in the New York/New Jersey harbor involves the consideration of various factors: complicated bathymetry, ambient wave field, various

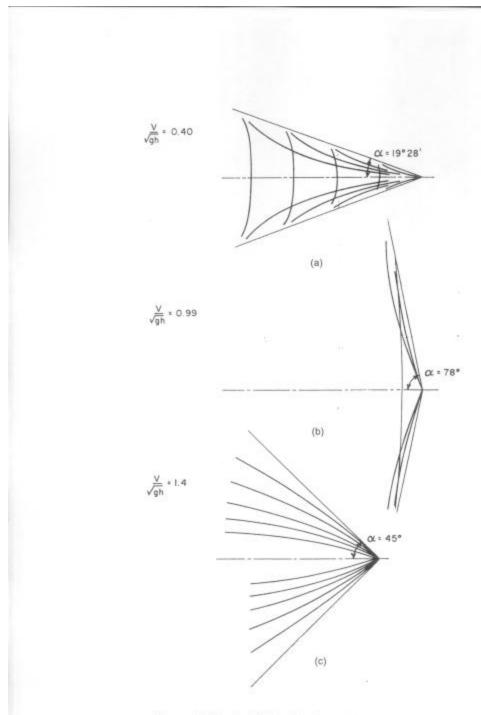


Figure 2. Effect of Water Depth on Wave Pattern

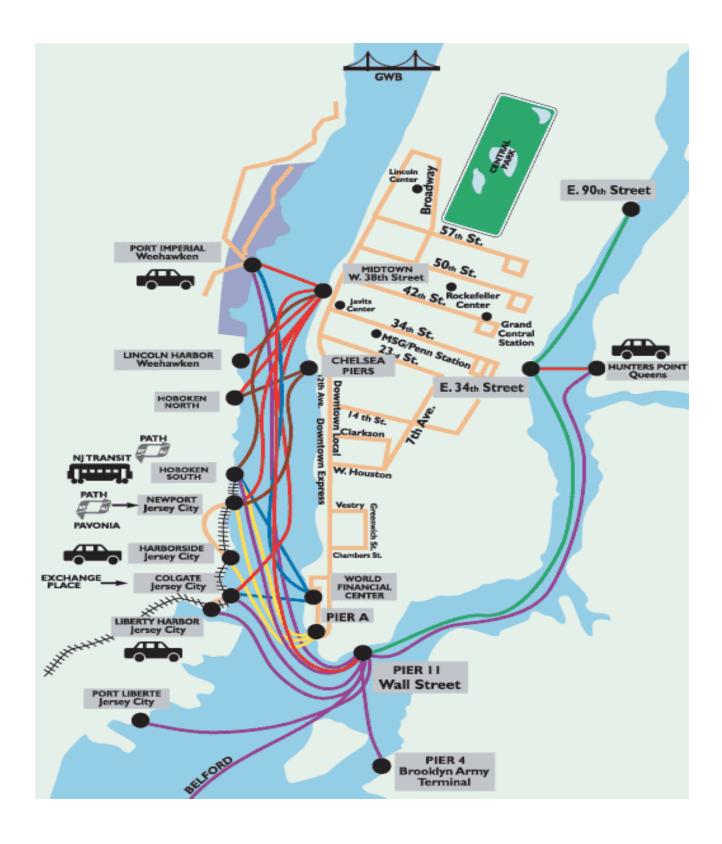


Figure 3. NYWW Ferry Service

types of vessels, their speed, acceleration and course changes. With this in mind, it was decided to study the problem by a combination of qualitative and quantitative field measurements, and laboratory measurements of wake wash from small-scale models. A quantitative description of the actual wave conditions found in the harbor is essential to any effort to address their impact. These measurements also provide the means by which the accuracy of small-scale laboratory experiments can be determined, which is necessary to ensure the veracity of any conclusions drawn from those and subsequent tests.

Initially, the use of computer models to study high-speed ferry wash was also considered. Computer models are available that study wave propagation in a semi-enclosed region with complicated bathymetry. The difficulty of this approach is to find an accurate description of the incoming waves generated by the ship in order to predict their propagation and impact. These waves do not only depend on the ship's geometry (displacement, draft, length, shape) but also on operational procedures (speed, trim, position of acceleration and course changes) and the water depth along the ship's route.

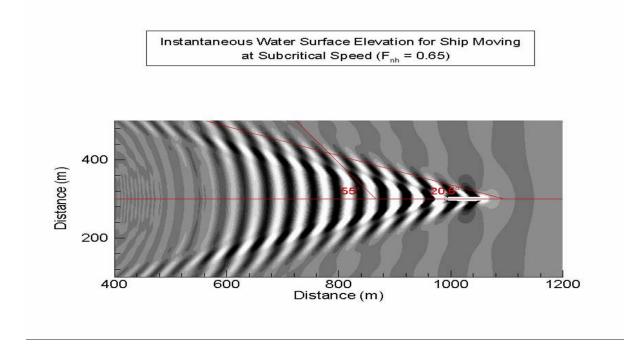


Figure 4a

Instantaneous Water Surface Elevation for Ship Moving at Transcritical Speed (F_{nh} = 0.9)

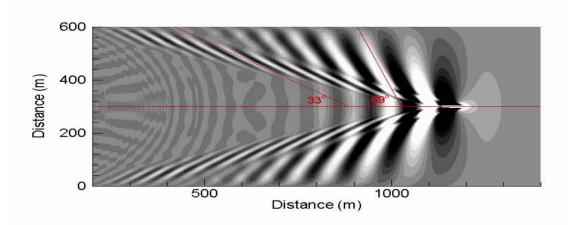


Figure 4b

Instantaneous Water Surface Elevation for Ship Moving at Supercritical Speed ($F_{nh} = 1.5$)

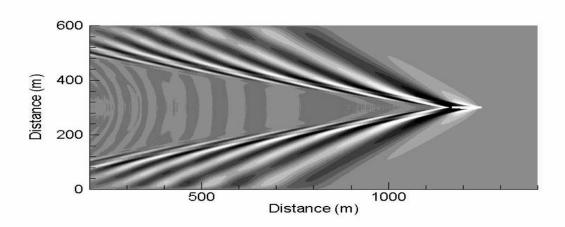


Figure 4c.

Currently computer models use semi-empirical methods to specify the wave wash generated by a moving body. Figures 4a, 4b and 4c show the wake pattern generated by a moving ship using computer models in the three Froude number regimes discussed earlier.

FIELD STUDIES

Observations

In order to characterize wave conditions in New York Harbor, a field study was undertaken in July, 2002. First, qualitative measurements were made of harbor waves by various fast ferry hull forms. The results of this qualitative assessment are available in the appendix. It became apparent that it would be necessary to determine if the waves observed near the banks of the river (where other users of the river spend most of their time) were the result of waves created local to a specific site or if the effects were the result of waves generated far from the site. To this end, pressure gauges were deployed for slightly over eight days beginning the afternoon of July 10th. Two gauges were situated so as to obtain time series pressure records that would, with the application of linear wave theory, provide a description of the typical wave heights and wave periods found in the harbor. The harbor bathymetry is characterized by a deep (~60 ft.) channel flanked in most areas by a narrow, flat, and shallow (~10 ft.) shelf. The presence of these two characteristic bottom types suggested that each should be instrumented as it is Ikely that waves would behave differently in the two areas. One gauge was placed at a depth of 36.7 feet below the still water line in the channel approximately 300 feet seaward of the pier head line, adjacent to the helix of the Lincoln Tunnel. The second gauge was placed at a depth of 13.8 feet inshore of the pier head line. The two gauges were located near the NY Waterways Lincoln Harbor terminal and as such near an active fast ferry route. The channel gauge, in particular, was very near (less than 500 ft) to an observed track of the Lincoln Harbor/ 38th Street route and also well exposed to waves propagating from other areas much farther away in the harbor.

Each instrument package consisted of a high-resolution strain gauge pressure sensor (accurate to within 0.05 decibar (0.073 psi) absolute) and data logger set to record time and pressure at 4 Hertz (4 samples per second) for the first 17 minutes of every 20 minute period starting at the top of the hour. The data loggers were synchronized with each other and with universal time (also called UT, here synonymous with Greenwich mean time or GMT) as given by the US Naval Observatory clock.

The static component of pressure (the part of the pressure signal that remains constant over a timescale much greater than the timescale of the waves) increases quickly and linearly with depth according to the familiar equation:

p=rgh

where:

p=pressure

r=density

h=distance below still water level (SWL).

Eight Day Surface Elevation vs. Time

The dynamic portion of pressure (the part of the pressure signal that is due to wave action) issued inversely related to both wave period and depth and this makes for a more complex elationship than the static equation. The effect is that subsurface pressure gauges will under report the fluctuations in surface elevation (leading to the underreporting of wave height) for shorter period waves as the depth of the gauge increases if the static equation were to be madvertently applied to the dynamic component. Therefore, linear wave theory was applied to correctly compute surface elevation from the pressure records subsequent to removal of the slowly varying components of pressure due to depth, tide and barometric pressure. The eight day surface elevation time series from the offshore gauge is given in Figure 5. The eight day surface elevation time series shows a strong diurnal papern of relatively early overnight wave heights contrasted against much larger daytime wave heights. The highest waves in the day occur during two reak periods. The first peak period of each day begins as a gradual increase starting at approximately 0530 EDT and peaking at approximately 0915 EDT.

Wave heights then gradually diminish, but only to levels well above the typical overnight values, until approximately 1245 EDT when they again begin to increase.

192

193

194

198

199

200

196

After the second and typically highest peak of the day at approximately 1745 EDT, the wave heights gradually diminish until they reach the typical overnight values some time shortly after 2330 EDT. This typical daily pattern is best seen in Figure 6. Overnight maximum wave heights range from 4 inches to 6 inches. The morning peak heights are typically between 12 inches and 16 inches on weekdays and 10 inches to 12 inches on weekends (Figure 7).

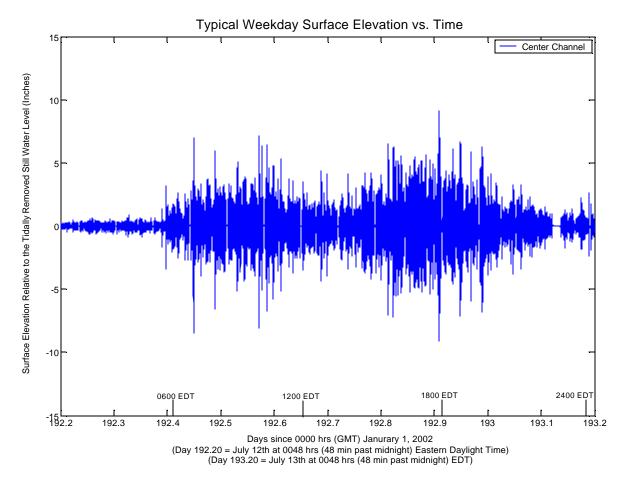


Figure 6

These values diminish to 8 inches to 12 inches during mid-day on weekdays and to 6 inches to 8 inches on weekends. The heights then increase again, sometimes beyond 20 inches on weekdays and up to 16 inches on weekends during the evening rush. In Figure 5, the weekend of 13-14 July 2002 occurs between Julian day 194.2 and 196.6. Closer examination of the records presented in Figure 6 and Figure 7 reveals that there are two modes of wave height present during the times of increased wave height. The first mode

appears as en elevated background or "noise" between spikes. The second mode appears as wave packets or "spikes" that are noticeably higher than the waves around them. The presence of the two modes suggests that wave conditions in any specific part of the harbor are the result of waves arriving from different sources. The background is characteristic of

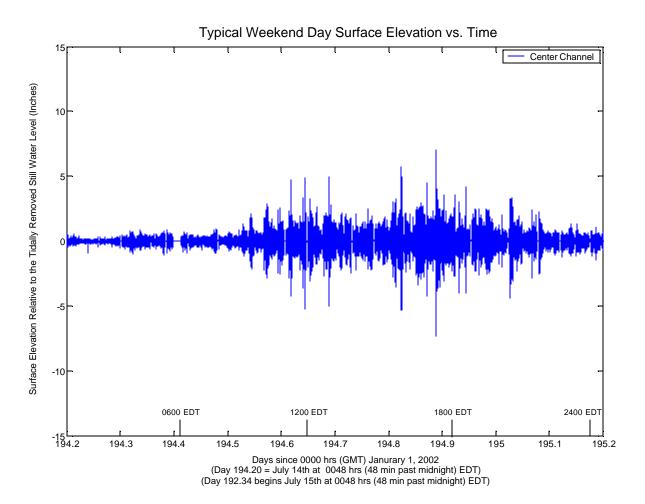
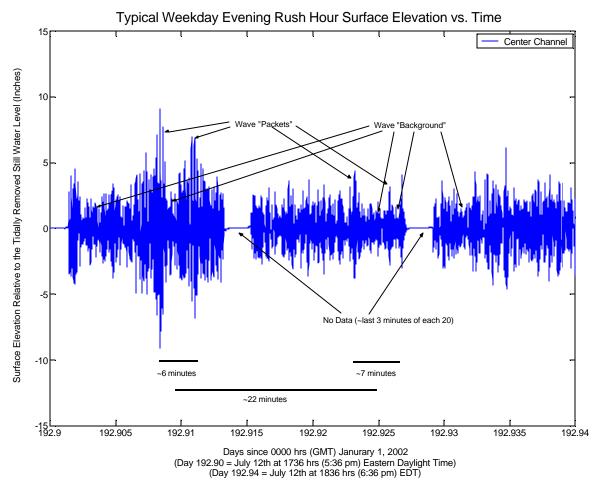


Figure 7

higher amplitude packets are characteristic of waves generated relatively close to the sampling site. The background can be thought of as wave packets that have had the distance and time to disperse and therefore the opportunity to decrease in height. Data depicted in Figure 8 demonstrates this repeating pattern of increased wave height alternating with background levels. Often and especially during the rush hours and midday, two large packets are found approximately 5 to 7 minutes apart. Also common during rush hour and midday is the presence of large packets (5 to 7 minutes apart) with the groups of packets separated by approximately 20 minutes.

Similar behavior is realized by both the inshore and center channel gauges: the relatively calm overnights are contrasted with energetic days on both the inshore and center channel gauges. Note that the weekend wave heights (Julian days 194.2 through 196.2) are approximately 35% lower than the typical weekday wave heights (see Figure 9). Also note that the inshore wave height is often greater than the center channel wave height. This phenomenon typically



occurs between 0600 EDT and 2200 EDT during the 8 day record. Between 2200 EDT and 0600 EDT, the center channel wave heights typically are comparable to or slightly exceed the inshore wave heights. When the inshore gauge does exceed the center channel gauge, it typically does so in a range that falls between 5% and 10%.

Figure 8

Until this point in the report, discussion of the observed waves has been limited to describing wave height. Wave height is the most important characteristic in determining wave energy.

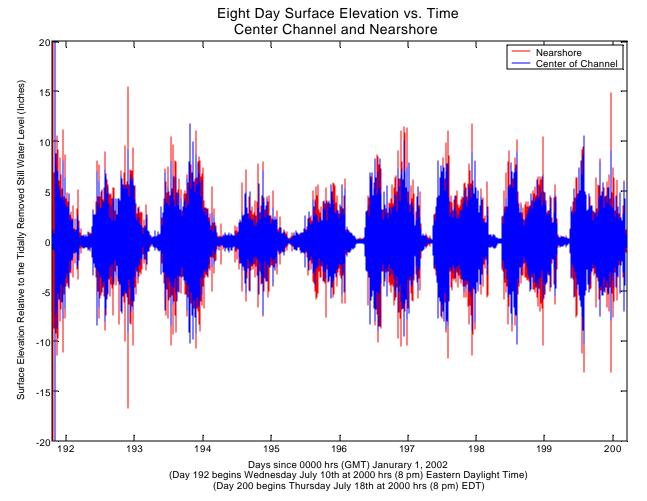


Figure 9

Of secondary but significant importance is wave period. Wave period is the length of time it takes for a complete wave to move past a static observer. This time is directly related to how fast the waveform is translating. In effect, period is a measure of the forward speed of the wave. Observed wave periods ranged from 1 to 10 seconds and were based on zero crossing of the pressure record. Histograms of period for different time periods are presented in Figure 10. The peak of the histogram falls in the 1 to 2 second range during a typical overnight hour. During the typical midday hour, the peak moves to the 1.5 to 3.0 second range and the number of occurrences in the 3 to 5 second range increases by nearly 50%. During a typical hour in the evening rush, the peak period again moves up, now to the

2.5 to 3.0 second range. During the evening rush, the number of occurrences of periods greater than 3.0 seconds is very similar to that which was observed during the midday, which is significantly greater than is observed in the calm overnight hours.

The increased occurrence of the longer period waves during the rush hours and midday are responsible for increased wave heights on the shelves that flank the river. The same effect is not observed in the overnight periods when there are far less of these long period waves. Longer period waves "feel" the bottom more than shorter period waves. As the wave moves into shallower water the wave experiences "shoaling" and the waveform modifies. The wave begins to move more slowly, but the period remains constant. The result is that the waves become taller.

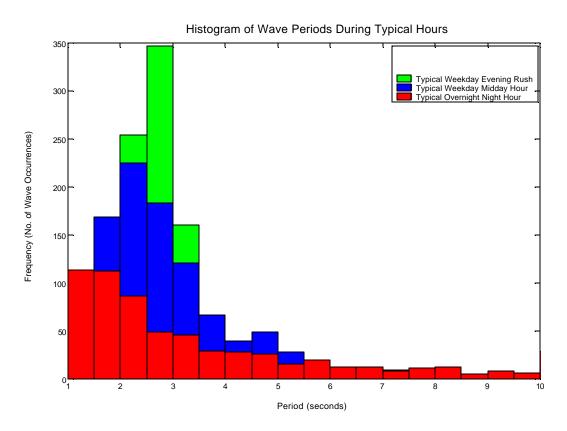


Figure 10

Discussion

The shallow shelves that flank the river are populated by numerous marinas that provide berthing to thousands of recreational vessels. The vessels range from outboards that are less than 20 feet in length to motor yachts in excess of 200 feet in length. The vast majority of recreational vessels range from 30 feet to 60 feet in length. Vessels are most sensitive to waves that are similar in length to the vessel itself. Wavelength is strongly related to wave period: the longer the period, the longer the wavelength. For the most commonly occurring waves during midday and rush-hours: 2.0 second wave periods will result in waves approximately 20.5 feet long and 3.5 second wave periods will result in waves approximately 62 feet long. As most recreational vessels in the harbor fall in this length range, these vessels are strongly affected by these waves.

LABRATORY STUDIES

Test Facility

Tests were conducted in the Davidson Laboratory High-Speed Towing Tank, which is 313 ft long, 12 ft wide and 5.5 ft deep. The towing carriage rides on a monorail located over the center of the tank; it is towed by means of a steel cable driven by an electric motor at the far end of the tank. The water temperature in the tank was maintained at 76 degrees for the duration of the test program.

Characteristics of Models

Four different vessels, whose characteristics are given in Table 1, were tested to study their wake characteristics in addition to the standard resistance and seakeeping performance characteristics.

Hull Type	Catamaran	Monohull	Catamaran	Catamaran
Length Overall	71.2 ft	65 ft	105 ft	90 ft
Length on Waterline	64.5 ft	63 ft	97.4 ft	81.7 ft
Beam Overall	27.5 ft	14 ft	28.4 ft	34 ft
Beam of Each Hull	7.8 ft		8.25 ft	9 ft
Draft	3.4 ft	3 ft	3.45 ft	5 ft
Base Displacement	134,400 lb	74,000 lb	195,610 lb	224000 lb
Wetted Surface Area	1423 sq. ft.	830 sq. ft.	2100 sq. ft	2048 sq. ft
Model Scale	1/12	1/12	1/20	1/16

Table 1. Characteristics of Vessels Tested

The first model, that of the 71 ft Catamaran, was tested in October 2000 but NY Waterway decided not to consider it for their fleet. The 65 ft Monohull, "The Sea Otter", was tested in April 2001 and NY Waterway currently operates 3 of these vessels. The 105 ft catamaran design was tested in July 2001 and NY Waterway is in the process of commissioning a few of these vessels. Finally, the 90 ft Catamaran that was tested recently in September 2002 will be part of the future NYWW fleet that is planned to operate between Middletown, NJ and

Battery Park City, NY. Figures 11a through 11d show the four models being tested in the tank.

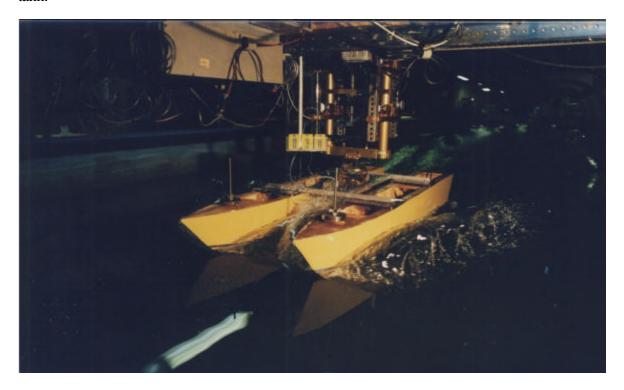
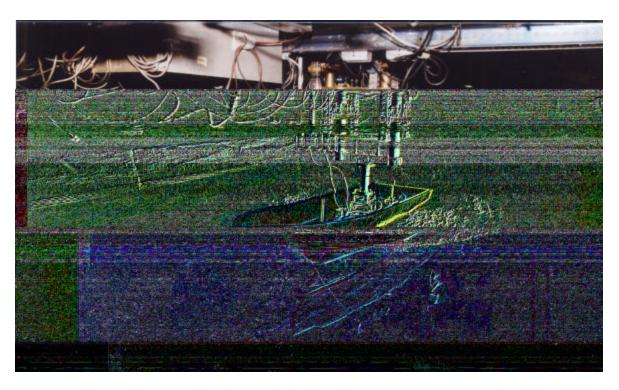


Figure 11a. 71 ft Catamaran



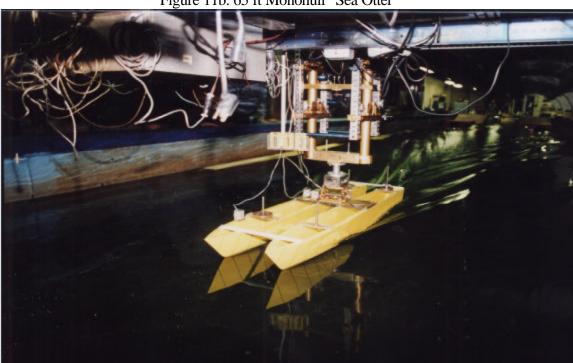


Figure 11b. 65 ft Monohull "Sea Otter"

Figure 11c. 105 ft Catamaran

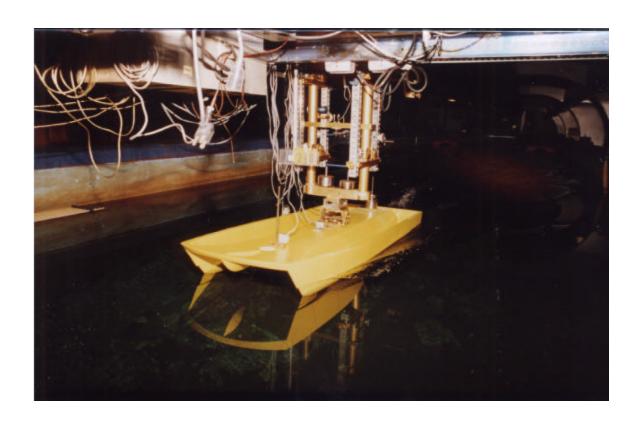


Figure 11d. 90 ft Catamaran

Instrumentation and Data Processing

The model was free to trim and heave, but fixed in yaw, roll, surge and sway. The vertical motion of the tow-point was measured using a motion transducer attached to the free-to-heave apparatus. Trim of the model keel relative to the horizon was measured using an inclinometer mounted on the connecting platform. Resistance was measured using a drag balance located directly above the pivot box. Two accelerometers were mounted near the bow and CG to record vertical acceleration in wave tests. Wake height measurements were made in calm water tests using two resistance-type wave probes at fixed locations in the tank. The two probes were located in that section of the tank where the model runs at constant speed and at transverse distances of 3 ft and 5 ft (model-scale) from the ship centerline. The time history of the wake was recorded as the model passed by. A video camera was located on the carriage and video recordings were made of each run. Still photographs using a camera mounted on the carriage were also taken for most of the runs.

The instruments to measure drag, trim, pitch, heave, accelerations and waves were calibrated prior to the tests by applying known loads, angles and displacements. All calibrations were linear and a least-squares technique was used to obtain calibration rates. Data were acquired at 250 Hz in a 100 ft "data trap" after the model had accelerated to steady speed, and transmitted by overhead cables to a shore-based PC for processing and storage. Model velocity was computed by measuring the time required to travel through the data trap.

Discussion

The full-scale wake heights measured from each of the model test are presented in Tables 2 to 5. Some of the typical trends that can be observed are: the wake heights increase with the displacement, the newer designs tend to have lesser wake heights, the wake heights are higher at the transition (hump condition) speeds and decreasse at higher speeds, wake heights depend on the location of the center of gravity and the running trim. To emphasize the

wake height variation with speed, the data from the 71 ft Monohull "Sea Otter" is presented in figure 12.

Run #	Spee (knots	Wake He	eights	Run #	Spee (knots	Wake H	eights
#	(KIIOLS	at 36	at 60	#	(KIIOLS	at 36	at 60
55 LT - 3 27 28 29 30 31	15 20 22 24 26	2.9 3 2.8 2.2 2.2	2.9 2.8 2.8 2 1.8	65 LT - 3 64 66 67 68 69	15 20 22 24 26	2.8 3.6 2.8 2.6 2.2	2.6 3.2 2.8 2.6 2.2
55 LT - 5 33 34 35 36 37 38	20 22 24 26 28 30	3.2 2.8 2.4 2 1.8 1.6	2.8 2.4 2.2 1.8 1.7 1.5	65 LT - 5 71 72 73 74 75	15 20 22 24 26	2.8 3.6 3 2.6 2.2	2.8 3.2 2.8 2.6 2.2
60 LT - 3 41 42 43 44	15 20 22 24	2.5 3 3.2 2.8	2.4 3 3 2.7	65 LT - 7 77 78 79 80 55 LT - 3	20 22 24 26	2.7 3.4 2.8 2.5	2.7 2.9 2.6 2.5
45 46 47 60 LT - 5	26 28 30	1.9 1.8 1.4	1.9 1.7 1.3	82 83 84 85	20 22 24 26	3 2.8 2.4 2	2.8 2.5 2.1 1.9
49 50 51 52 53 54 55	15 20 22 24 26 28 30	2.5 2.9 3.2 2.8 2.4 2 1.8	2.5 2.9 2.8 2.8 2.3 2 1.7	50 LT - 5 88 89 90 91 92 93	15 20 22 24 26 28	3.2 2.8 2.5 2 1.9 1.5	2.9 2.6 2.3 1.7 1.6 1.3
60 LT - 7 59 60 61 62	20 22 24 26	2.7 3.2 2.8 2.4	2.7 2.8 2.6 2.2	94	30	1.4	1.2

Table 2. Wake Heights - 71 ft (at different displacements and LCG

Run# No.	Velocity (kn)	Wake Hoat 36ft	eight(ft) at 60ft	Run# Velocity Wake Height(ft) No. (kn) at 36 ft at 60 ft
73,990lb.	- 39.8 ft			62,500 lb 39.8 ft
4	15	2.8	2.1	49 20 2.5 2.0
5	20	2.9	2.3	50 22 2.4 1.6
6	22	3.1	2.0	52 24 2.2 1.3
7	24	2.5	1.7	53 26 2.2 1.2
8	26	2.2	1.6	54 30 2.3 1.2
9	28	2.4	1.6	55 32 2.2 1.1
10	30	2.6	1.5	40.8 ft
11	30 32			
		2.7	1.4	63 30 2.4 1.2
repeat che		0.7	4.0	Table value 2 75% intermediate of 62 500 lb
13	24	2.7	1.6	Tests using 2.75" interrupters at 62,500 lb. 1/16" projection - 39.8 ft I CG
Tests with	h LCG varia	ation at 73.	.990 lb.	57 15 1.9 0.8
37.8 ft				59 26 1.7 1.3
15	26	2.4	1.6	1/16" projection - 40.8 ft LCG
38.8 ft	20	2.7	1.0	61 26 1.9 1.3
<u>30.6 11</u> 17	26	2.3	1.6	62 30 1.9 1.1
	20	2.3	1.0	
41.8 ft	00	0.7	4.0	<u>1/32" projection - 40.8 ft LCG</u>
21	26	2.7	1.8	67 30 1.8 0.9
<u>40.8 ft</u>				-
19	26	2.7	1.6	Tests using interrupters at 73,990 lb.
23	28	2.7	1.5	2.75" long - 1/32" projection - 39.8 ft I CG
24	30	2.7	1.5	70 26 1.2 1.8
25	32	2.7	1.5	<u> 1.4" long - 1/32" projection - 39.8 ft LCG</u>
				72 26 2.3 1.6
49,640 lb.	- 39.9 ft			73 30 2.3 1.4
27	10	0.7	0.2	1.4" long - 1/32" projection - 40.8 ft I CG
28	15	1.5	0.7	75 30 2.3 1.3
29	20	2.0	1.6	76 26 2.5 1.6
30	22	1.9	1.3	
31	24	1.7	1.1	Tests using Trim Wedges at 73,990 lb. And 39.8 ft
32	26	1.5	1.2	3.5"X1" - 5 deg. Wedges
33	28	1.8	1.0	79 26 2.0 1.5
34	30	1.8	1.0	3.5"X1" - 3 deg. Wedges
35	32	1.8	8.0	82 30 2.4 1.4
repeat che				
36	24	1.8	1.2	
49,640 lb.	- 40.9 ft			
40	26	1.8	1.0	
41	28	2.0	1.0	
42	30	1.9	0.9	
43	32	1.8	0.9	
44	40	1.6	0.7	
45	42	1.5	0.7	
+0	+∠	1.5	0.0	

Table 3. Wake Heights - 65 ft (at different displacements and LCGs)

Run No.	Vs (kn)	Wake H at	leights at 100	Run No.	Vs (kn)	Wake I at	Height at 100
195,610 II	b -			195,610	lb -		
9	10	0.6	0.5	49	20	4.0	3.2
10	15	1.5	0.9	50	24	2.5	2.0
11	20	2.2	1.0	51	27	2.2	1.9
12	22	2.6	1.5	52	30	1.9	1.6
13	24	2.6	2.5	55	34	1.6	1.1
15 14	26 28	2.5 2.2	1.9 1.8	150,850 I	'h -		
16	20 30	2.2 1.8	1.6	1 50,650 1 57	19	3.1	1.3
10	30	1.0	1.0	58	20	2.3	1.7
195,610 II	b -			59	24	2.0	1.5
19	20	2.9	2.2	60	28	1.7	1.4
21	24	2.7	2.4	61	30	1.5	1.2
22	26	2.4	2.1	62	32	1.4	1.1
23	28	2.0	1.8	64	36	1.2	0.9
24	30	2.0	1.5	66	40	1.1	8.0
25	32	2.0	1.4	150 050 1	L		
26 27	34 36	1.8 1.6	1.4 1.1	150,850 l	0 20	2.2	1.7
28	38	1.6	1.1	68 69	20 24	2.2 2.1	1.7
29	40	1.6	1.0	70	24	2.1	1.5
30	41	1.6	1.0	70 71	28	1.8	1.3
00	• • •	1.0	1.0	72	30	1.6	1.2
* Chines	Widened	l near the		73	32	1.5	1.1
195,610 II				75	41	1.3	8.0
32	20	1.6	1.2		. =		
33	24	2.5	1.9	225,000 I		0.0	4.4
34	28	1.9	1.8	77 70	20	2.3	1.1
35 37	30 32	1.8 1.7	1.6 1.4	78 79	24 28	2.9 1.7	2.2 2.0
38	34	1.7	1.4	80	30	2.4	2.0 1.7
30	34	1.7	1.2	81	32	1.9	1.7
195,610 II	b -			82	34	1.8	1.4
40	20	2.2	2.1	~_	•		
41	24	2.6	1.9	225,000 l	b 64		
44	26	2.0	1.8	84	24	2.9	2.2
45	30	1.9	1.6	85	28	2.3	2.1
46	32	1.8	1.3	86	32	2.0	1.4

Table 4. Wake Heights - 105 ft Catamaran (at different displacements and

Run #	Vs (knots	Wake Height (at 80	Run #		Wake Height (at 80
100 LT -	Level		110 LT - I	Level	
1	0	0.0	19	0	0.0 3.2
2	10 15		20 21	20 25	
4	20		22	27	
5 6	25 27		23 24	30 32	
7	30	1.3	25	35	1.2
8 9	32 35		26 27	37 40	
10	37	1.1			0.0
11	40		90 LT - Le	evel	
12	30	1.2	28	0	0.0
			29	20	
100 LT - 2	2 deg		30	25	2.5
14	0	0.0	31	27	
15	20	3.5	32	30	1.2
16	25		37	32	
17	30	1.1	34	35	
18	35	8.0	35	37	
			36	40	0.9

Table 5. Wake Heights - 90 ft (at different loads and

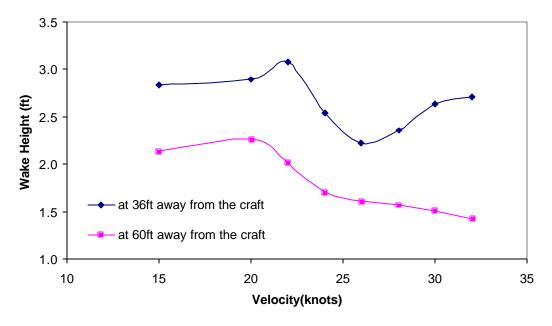


Figure 12. Wake Height Vs. Speed (71 ft Monohull at 73,990 lb. - 39.8 ft)

RESULTS AND DISCUSSION

The wake heights and periods found in the field measurements agree well with what was predicted to occur in the less than optimum regimes observed during the physical model tests. For this reason it would be expected that modification of operational parameters such as speed and trim to be more in line with the optimum values predicted by the physical model tests would lessen wakes created by a particular vessel. For vessels currently operating in their most inefficient regimes, the potential reduction in wake energy can be substantial.

The largest amount of wake energy created per unit time, by far, occurs during the transition from displacement to planing mode. This was observed in the physical model tests and suggested in the qualitative field study. In many cases (especially the newer hulls), faster speeds will result in lower wave energy. Again, with the guidance provided by physical model tests of hulls, these optimum speeds must be known and adhered to by vessel operators whenever possible (safe) to minimize wake. As little time as possible should be

spent in the transition zone. Again, for vessels that are currently being operated for long periods of time at the very high end of displacement (very low end of planing) substantial decreases in wake energy will be possible by this optimization. This decrease in wake energy can come from either running more slowly or, somewhat counter intuitively, going faster.

The qualitative field study also strongly suggested that sharp turns in the transition phase could have pronounced effects in focusing wave energy, especially to the inside of turns. The qualitative evidence is strong enough on its own in this specific area to warrant the minimization of any sharp turns during the transition phase if any wake sensitive areas are located on the inside of the turn.

Wave shoaling is taking place during at least some stages of the tide in the shallowest areas of the flank shelves, some of which contain marinas. Deepening (dredging) these specific areas has the potential to reduce wave heights by 30% in some of the shallowest regions. Deepening by itself will not completely mitigate any wake problem in this harbor, but should be considered part of the total approach in so far as it will prevent exacerbating the situation. In cases where a marina is already extremely shallow, deepening can substantially reduce wave height (30%).

In places where reflective shorelines (vertical or near vertical walls) border water deeper than 2 feet MLLW, most of the incoming wave energy is simply reflected back into the Harbor. Efforts should be taken wherever possible to limit reflective shorelines. Again, simply replacing reflective shorelines with dissipative shorelines will not completely mitigate the wake problem, but will prevent exacerbating the situation and is an important part of any total approach.

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RECOMMENDATIONS

The effect of waves in New York Harbor will not be mitigated by any one solution. A cooperative and combined approach from ferry operators, marina operators, and regulators will be necessary for all the users of the harbor to coexist and potentially thrive.

For The Ferry Operators

Many of the most wake sensitive areas may only be affected by 1 or 2 ferry routes. Careful course selection on these routes to 1) minimize the transition time while adjacent to or pointing at the wake sensitive area or 2) avoid turning with the wake sensitive area inside the turn, should make a noticeable difference in the sensitive area. In order to be effective, careful monitoring of the actual tracks and water speeds will need to occur to ensure that vessel operators are in fact complying with the guidelines developed for each route. In general, a ferry should proceed from the dock to the center of the channel well below transition (well within displacement mode), then make its turn to go along channel, rapidly accelerate to optimum planing speed until adjacent to the next stop, decelerate to a speed well within displacement mode, then turn into dock for landing.

Vessel route assignment should be made with wake characteristics in mind: use the most inefficient hull forms in the most insensitive areas and the most efficient hull forms in the most sensitive areas. Ideally, the most inefficient hull forms will be eventually retired and replaced with efficient hull forms. Alternatively, it may be possible as a stopgap, to refit older vessels with active trim control or sufficient horsepower to ensure the most efficient planing angle and/or speed.

Determine exactly what the most wake efficient points of operation are for each of the vessel classes and then operate within this speed range with as little time as possible in the transition

phase. Again, monitoring of the entire fleet for compliance will be key, as will training of the vessel operators as to what is needed for each hull form they will operate.

In waterways elsewhere in the world where wake wash problems were experienced, arbitrary speed restrictions were imposed for existing craft. These restrictions not only affect the profitability of the operator by increasing the journey time, but also in many cases may not actually reduce the wake impact. This was observed in the field and can be seen from many of the physical model measurements. Therefore, we do not recommend speed restrictions without field or laboratory measurements showing considerable reduction in wake wash energy.

For The Marina Operators

Marina operators must be permitted to build wave protection systems that are substantial enough to do the job. Any such system should be capable of protecting to a sufficient degree the contents of the marina from waves over 20 inches in height with periods over 4.25 seconds. Examples include continuous wave screens that reach to the bottom, and wide wave barriers of the order of no less than ½ the wavelength, both of which surround the marina as completely as possible. Reflective surfaces at the side banks should be avoided as much as possible. At least one entire side of a box-shaped marina should be dissipative. Openings to the harbor should be as small as possible and screened if possible.

Every effort should be made to keep the water depth deeper than 3 feet MLLW to minimize shoaling. .

For the Regulators

Remember that a harbor wide, multi-user solution will be necessary.

Assist marinas to deepen by streamlining permitting and assisting with disposal solutions.

Ease permitting requirements for breakwaters and allow them to be based on effective designs.

Encourage the building of wave dissipative shorelines at every opportunity. This means for any new harbor side construction and not just ferry terminals and or marinas.

For the General Public

Education will be necessary on the main safety issue: there will be waves in a commercial harbor. As always no opportunity should be lost to make the points that larger vessels are typically moving much faster than they appear, and smaller vessels are very difficult to see.

APPENDIX

Qualitative Observational Study

To obtain a better understanding of the wake patterns of existing NYWW craft, it was decided to perform initial qualitative observational studies from on-board the craft in their normal operating conditions. Permission from the New York Waterway for the study was obtained and trips were taken on their fleet over a period of two days. A GPS, Camera, log book, and video camera were taken to record the observations.

Name	Description	Route
Abraham Lincoln	95 ft Monohull	Hoboken South to WFC
LaGuardia	** ft Catamaran	WFC to Colgate
Brooklyn	** ft Catamaran	Colgate to 38 th St
New Jersey	95 ft Monohull	38 th St to Lincoln Harbor
New Jersey	95 ft Monohull	Lincoln Harbor to 38 th St
Thomas Jefferson	95 ft Monohull	38 th St to Port Imperial
Thomas Jefferson	95 ft Monohull	Port Imperial to 38 th St
Adventurer	** ft Monohull	38 th St to Hoboken North
Sea Otter	65 ft Monohull	Colgate to Pier 11
Sea Otter	65 ft Monohull	Pier 11 to Colgate

Figures 13(a) to 13(f) show the photographs of wakes behind some of these craft.



Figure 13a. Abraham Lincoln – Transition

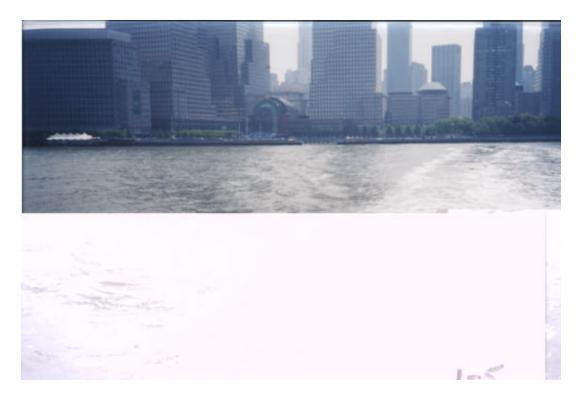


Figure 13b. La Guardia – Planing



Figure 13c. Brooklyn – Planing



Figure 13d. New Jersey – Transition



Figure 13e. New Jersey – Planing



Figure 13f. Adventurer - Planing





SYNOPSIS

An examination of wake and its properties as they apply to the New Jersey/ New York Harbor Complex was undertaken. The amount of wave energy present was quantified over the course of several days for one typical harbor location. Scaled laboratory experiments were conducted on the actual hull forms used in the New Jersey/ New York Harbor Complex and results compared with field observations. The most promising areas for wake reduction were narrowed and identified. In general, wake is the resulting pressure disturbance created by a body moving through a fluid. In the case of vessels on water, wake appears in the familiar form of surface waves. The magnitude (height), wavelength (the distance between similar points on two waves in sequence e.g. crest to crest), and direction of propagation are functions of both vessel and environmental properties. Vessel properties germane to wake generation include speed, heading, displacement (weight), loading (trim), and hull form. Environmental factors affecting wake propagation include speed and direction of wind and currents, water depth, and geometry of the shore. A compressed set of the conclusions contained in the full report is included.

RECOMMENDATIONS

The effect of waves in New York Harbor will not be mitigated by any one solution. A cooperative and combined approach from ferry operators, marina operators, and regulators will be necessary for all the users of the harbor to coexist and potentially thrive.

For The Ferry Operators

- Careful course selection on specific routes to manage: 1) time in transition and 2) direction of wake propagation, has the potential to make noticeable improvements in the sensitive area. Careful monitoring of the actual courses, speeds, and water conditions will need to occur to ensure that vessel operators are in fact complying with the guidelines developed for each route and the modifications have the intended effect.
- Vessel route assignment should be made with wake characteristics in mind: use the most inefficient hull forms in the most insensitive areas and the most efficient hull forms in the most sensitive areas.

- Modernize the most inefficient portions of the fleet at every opportunity. As a stopgap
 refit older vessels with active trim controls or sufficient horsepower to ensure the most
 efficient planing angle and/or speed.
- Determine exactly what the most wake efficient points of operation are for each of the vessel classes and then operate within this speed range as much as possible.

For The Marina Operators

- Marina operators must be permitted to build wave protection systems that are substantial enough to protect to a sufficient degree the contents of the marina from waves over 20 inches in height with periods up yo and including 4.25 seconds.
- Reflective surfaces at the side banks should be avoided as much as possible.
- Openings to the harbor should be as small as possible and screened if possible.
- Every effort should be made to keep the water depth deeper than 3 feet MLLW to minimize shoaling.

For the Regulators

- Remember that a harbor wide, multi-user solution will be necessary.
- Assist marinas to deepen by streamlining permitting and assisting with disposal solutions.
- Ease permitting requirements for breakwaters and allow them to be based on effective designs.
- Encourage the building of wave dissipative shorelines at every opportunity. This means for any new harbor side construction and not just ferry terminals and or marinas.

For the General Public

Education will be necessary on the main safety issue: there will be waves in a
commercial harbor. As always no opportunity should be lost to make the points that
larger vessels are typically moving much faster than they appear, and smaller vessels are
very difficult to see.